Work xx (2023) x–xx
DOI:10.3233/WOR-220514
IOS Press

Validation of a temperature-humidity index (Humidex) in evaluating heat stress at a tile factory in Iran

Akbar Barzegar[a,b], Amin Babaei Pouya[c], Amir Hossein Hashemian[b], Farshad Nadri[a], Mohsen Poursadeqiyan[c,*] and Ali Omidi[b,d]

[a]*Department of Occupational Health, School of Health, Kermanshah University of Medical Sciences, Kermanshah, Iran*

[b]*Research Center for Environmental Determinants of Health (RCEDH), Health Institute, Kermanshah University of Medical Sciences, Kermanshah, Iran*

[c]*Department of Occupational Health, School of Health, Ardabil University of Medical Sciences, Ardabil, Iran*

[d]*Department of Occupational Health and Safety Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran*

Received 14 September 2022
Accepted 20 July 2023

Abstract.

BACKGROUND: Several heat indices have been developed in industrial health, but each has its limitations.

OBJECTIVE: The objective of this article is to determine the validity and applicability of a temperature-humidity index, named Humidex compared with the Standard Wet-Bulb Globe Temperature (WBGT) index (ISO 7243).

METHOD: This cross-sectional study was conducted in the summer of 2019, in a tile factory in the west of Iran. 59 measurements were performed in 8 different workstations. Environmental parameters including natural wet bulb temperature (T_{nw}), dry bulb temperature (T_a), globe bulb temperature (T_g), and heat stress (WBGT) were measured. Humidex was calculated according to an equation. SPSS software (version 16) was used for data analysis.

RESULTS: There was a high correlation between Humidex and WBGT in the estimation of heat stress (R=0.912, P<0.001). The Kappa Coefficient between Humidex and WBGT was 0.298, P=0.001.

CONCLUSION: Humidex is highly correlated with WBGT. Humidex can be used instead of the WBGT index, especially in hot and humid environments.

Keywords: Thermal, heat stress, comfort, climate changes, Humidex, global warming

1. Introduction

Heat stress is a major occupational risk factor [1–4], especially in the tile industry, where workers work with high-temperature furnaces. According to the American Conference of Governmental Industrial Hygienists (ACGIH), heat stress is the sum of heat from metabolic activity, environmental factors (i.e., air temperature, humidity, air movement, and radiant heat), and clothing type [5]. Environmental heat and metabolic heat can cause complications such as heat strain, increased accident risk, Heat stroke risk, neurological and mental symptoms, and decreased efficiency [6, 7]. The first step to prevent the adverse effects of heat stress is to measure heat stress and determine risk. So far, several indices have been proposed to evaluate heat stress in workplaces, and the

*Address for correspondence: Mohsen Poursadeqiyan. E-mails: m.poursadeghian@arums.ac.ir; poursadeghiyan@gmail.com.

Wet Bulb Globe Temperature Index (WBGT) is one of the most important indices. This index is related to the body's physiology in hot settings [8, 9]. The International Organization for Standardization (ISO) has introduced a standard method named ISO 7243 to measure WBGT. This index is a combination of environmental factors, including radiant temperature (Tg), arid temperature (Ta), and natural wet temperature (Tnw) [10]. In the study by Srivastava et al., heat stress in a glass factory in India was assessed by using WBGT, Mean Radiant Temperature (MRT) and Corrected Effective Temperature (CET) indices; and the results showed that WBGT was a suitable index in determining the rest/activity cycle. Despite its advantages, such as reliability and broad applicability, the WBGT index is not applicable in high heat, where sweat evaporation is limited, because of high humidity or low air flow. Interpretation of the values obtained from the WBGT index requires a detailed assessment of individual activities, clothing, and other factors; and neglecting these factors may lead to major mistakes in the interpretation of adverse effects of heat stress [11]. Numerous indices have been developed and tested in recent years [12]. One of the indices used for measuring heat stress is called Humidex. Humidex was introduced by Richardson and Masterton in 1979 [13] to determine thermal comfort conditions by using two important parameters; which are temperature and relative humidity or dew point. The Humidex index was originally used to predict weather conditions, and thereafter due to its convenience, simplicity of use and not needing complex measurement tools broadly applied for heat stress assessment in workplaces. The Humidex index equation is based on two assumptions associated with the human body's temperature-regulating system which include: 1) Normal temperature is 27-30°C for a naked person exposed to mild airflow. 2) Human physiology is unable to heat acclimation if the environmental temperature exceeds 32°C in the humidity above 75% [14]. In 2001, the Occupational Health Clinics Ontario Workers (OHCOW) used this index to evaluate heat stress [15]. The many employers who used WBGT to measure heat stress in their workplace complained about the complexity and impracticability of the WBGT index, and this led to the expansion of using Humidex. Humidex is an experiential index that is equal to the dry temperature in degrees Celsius. The leveling of the Humidex index for thermal comfort conditions is as follows; The index value below 29 indicates discomfort in few workers, the value between 30 to 34 indicates the feeling of relative weakness in the workers, the value between 35 to 39 indicates severe weakness (it is better to limit heavy physical activities), the value between 40 to 45 feeling of general weakness (it is dangerous and physical activity should be avoided), the value between 46 to 53 indicates a serious risk (must stop physical activity), and the value more than 54 indicates imminent heat stroke (risk of death) [16]. The study by Rana et al. expressed that Humidex is a summary of temperature and humidity and measure easily, and the credible index for predicting thermal comfort in indoor environments with high levels of humidity [17]. Another study conducted by Barnett et al. based on deaths that occurred in 107 US cities from 1987 to 2000, compared 14 different heat stress measurement methods by using humidity and temperature models. No model was found to be better than other models in predicting the mean temperature which resulted in death in different age groups, cities, or seasons [18]. This study aimed to validate Humidex for the evaluation of heat stress in industrial settings.

2. Methods

This study was conducted in a tile manufacturing plant located in the west of Iran. The manufacturing hall was divided into eight main units in the tile factory, and 59 measurements were performed in these units on non-holidays (Table 1). The points suitable for measurement were determined by the presence of workers at the workstations and the heat sources in the units. At each workstation, environmental parameters, including natural wet bulb temperature (Tnw), dry bulb temperature (Ta), globe bulb temperature (Tg), and WBGT index were measured by using a Heat Stress WBGT meter - HB3279-03 (manufactured by Casella Solutions, UK). Measurements were performed between 10 am and 2 pm. The WBGT meter device was placed at a height of 110 cm for 30 minutes in different workstations. The temperature was similar at head and ankle height and was therefore not repeated at these heights. Environmental parameters were read and recorded after thermal equilibrium was established. Calibration was performed before sampling according to catalog instructions. The tile manufacturing plant workstations were located in indoor spaces (without solar radiation). WBGT (°C) was measured and calculated according to Equation 1 [19, 20].

Table 1
The number of measurements in the different units at the tile factory

Factory units	n
Press	13
Bisque Firing	11
Glaze Firing	11
Sorting and Packing	7
Glaze preparation	4
Glazing	4
Pre-grinding of hard raw materials	6
Spray Dryer	3

$$WBGT = 0.7Tnw + 0.3Tg \quad (1)$$

In this equation, Tnw, and Tg represent natural wet temperature, and radiant temperature in Celsius degrees, respectively. Humidex was calculated according to Equation 2.

$$Humidex = T + 0.5555 \times \left[\left(6.112 \times \left(\frac{exp\,(7.5 \times T)}{237.7 + T}\right) \times \left(\frac{RU}{100}\right)\right) - 10\right] \quad (2)$$

In this equation, T and RU represent air temperature (in Celsius) and relative humidity (in percentage) respectively. The temperature and humidity ranges were defined and the correlation between indices was calculated in these defined ranges. Relative humidity was categorized as less than 25%, 25-35%, and more than 35%; and the temperature was categorized as less than 30°C, 30-35°C, and values higher than 35°C. To compare the indices, the threshold value of WBGT for people adapted to average working conditions and with light summer clothes was considered 28°C [21], and Humidex was considered 35°C. Table 2 shows different heat stress levels of the WBGT and Humidex indices [22]. The normality of quantitative variables was checked using the Kolmogorov-Smirnov test. Scatterplots, Pearson correlation coefficients, and Kappa coefficients were performed to evaluate the statistical relations and agreement. SPSS 26 statistical software was used to analyze the data. P-values less than 0.05 were considered statistically significant.

3. Results

The WBGT values ranged between 19 and 32°C and Humidex values ranged between 27 and 49°C. In the WBGT index, 23.7% of the data were above the threshold limit (TLV=28°C). In Humidex, 59.3% of the data were above the threshold limit (TLV=35°C). Table 3 lists the values of thermal parameters in different units. As can be seen in Table 4, the highest values of the WBGT index were in the Glaze Firing and Bisque Firing units. Moreover, the highest value of Humidex was in the Glaze Firing unit; and the Pressing unit and Bisque Firing unit shared the second rank. The lowest value of the WBGT index was measured in the spray dryer unit, and the lowest value of Humidex was measured in the Glazing unit. The correlation between WBGT and Humidex was evaluated in different ranges of air temperature (less than 30, 30-35, and above 35°C) and relative humidity (less than 25, 25-35, and above 35%). The calculated agreement coefficient (Kappa-value = 0.3) indicated a relatively poor agreement between WBGT and Humidex. However, by considering the Pearson correlation coefficient (R = 0.912), a very high agreement was observed between the two indices (P-value < 0.001) (Table 5). According to the results of the WBGT index, 23.7% of the measurements in different manufacturing parts fell in the slight heat category; however, based on the results of Humidex, 25.4% of the measurements fell in the slight category, 22% fell in moderate category and 11.9% of them fell in the strong category (Table 6). The correlation between WBGT and Humidex was R = 0.912, P < 0.001) and the scatter plot can be seen in Figs. 1 and 2.

Table 2
Heat stress levels of WBGT and HUMIDEX [22]

Heat stress levels	WBGT (°C)	Humidex (°C)
No heat stress	<28	<35
Slight	28–32	35–40
Moderate	33–35	41–45
Strong	36–38	46–54
Extreme	>38	>54

4. Discussion

According to the results, the WBGT values ranged between 19 and 32 and Humidex values ranged between 27 and 49. In the WBGT index, 23.7% of the data were over the threshold limit (28°C) and 76.3% were lower. Also, for Humidex, 59.3% of the data were over the threshold limit value (35°C) and 39.7% were lower. The highest values of the WBGT index were obtained in the Bisque Firing and Glaze Firing units. Also, the highest value of Humidex was obtained in the Glaze Firing and the pressing unit,

Table 3
Thermal parameter distribution in the different units of the tile factory (n=59)

Factory units	T_a°C Mean (Range)	T_g°C Mean (Range)	T_{nw}°C Mean (Range)	RU % Mean (Range)
Press	33(25-40)	34(26-41)	21(16-26)	35(25-52)
Bisque Firing	34(25-42)	36(24-44)	23(17-27)	31(25-39)
Glaze Firing	36(29-42)	37(28-44)	23(19-27)	29(24-36)
Sorting and Packing	32(26-38)	33(27-38)	21(17-25)	34(31-39)
Glaze preparation	30(26-34)	30(26-34)	21(18-23)	41(35-50)
Glazing	27(25-31)	27(25-32)	19(17-20)	28(26-30)
Pre-grinding of hard raw materials	28(25-30)	33(26-38)	18(16-21)	32(28-37)
Spray dryer	27(26-28)	27(26-28)	18(17-19)	38(35-42)

Table 4
WBGT and HUMIDEX distribution in the different units of the tile factory (n =59)

Factory units	Test number	WBGT (°C)		Humidex (°C)	
		Mean ± SD	Range	Mean ± SD	Range
Press	13	25 ± 3	19-30	39 ± 7	28-49
Bisque Firing	11	27 ± 3.3	21-32	39 ± 6	27-47
Glaze Firing	11	27.2 ± 3	22-31	40.5 ± 4.7	33-47
Sorting and Packing	7	25 ± 3.6	20-29	37 ± 6	30-44
Glaze preparation	4	23.6 ± 2.9	21-26	36 ± 4.5	31-40
Glazing	4	21.5 ± 1.9	19-24	29 ± 3	27-33
Pre-grinding of hard raw materials	6	22.4 ± 2.5	19-25	31 ± 2.9	27-35
Spray dryer	3	20.5 ± 1.1	19.6-22	31 ± 2.2	29-33

Table 5
The correlation between WBGT and Humidex in different air temperature
and relative humidity in the Tile factory

Dry temperature (°C)	Relative humidity (%)			Marginal
	<25	25-35	>35	
<30	N=0	N=14 R=0.519, P=0.057 Sen=100%	N=10 R=0.88, P=0.001 Sen=90%	N=24 R=0.616, P=0.001 Sen=95.8%
30-35	N=1	N=9 R=0.966, P<0.001 Sen=11.1%	N=5 R=0.721, P=0.170	N=15 R=0.814, P<0.001 Kappa =0.01, P=0.782 Sen=7.1%
>35	N=2	N=12 R=-0.973, P<0.001	N=6 R= 0.353, P=0.492	N=21 R=0.738, P<0.001
Marginal	N=3 R=0.999, P=0.033 Low Cases	N=35 R=0.960, P<0.001 Kappa=0.316, P<0.001 Sen=53.6%, Spe=100%	N=21 R=0.925, P<0.001 Kappa=0.222, P=0.105 Sen=50%, Spe=100%	N=59 R=0.912, P<0.001 Kappa =0.298, P=0.001 Sen=51.1%, Spe=100%

and the Bisque Firing unit was the second rank. The lowest value of the WBGT index was obtained in a spray dryer unit, and the lowest value of Humidex was obtained in the Glazing unit. In the study by Hosseini et al. in a tile manufacturing industry to evaluate heat stress, the highest values of the WBGT index were obtained in Bisque and Glaze Firing, and this was consistent with the results of this study [23]. Humidex

Table 6
Different classes of Humidex vs. WBGT in the tile factory (*n*=59)

Heat stress classes	WBGT		Humidex	
	n	%	n	%
No heat stress	45	76.3	24	40.7
Slight	14	23.7	15	25.4
Moderate	0	0	13	22
Strong	0	0	7	11.9
Extreme	0	0	0	0

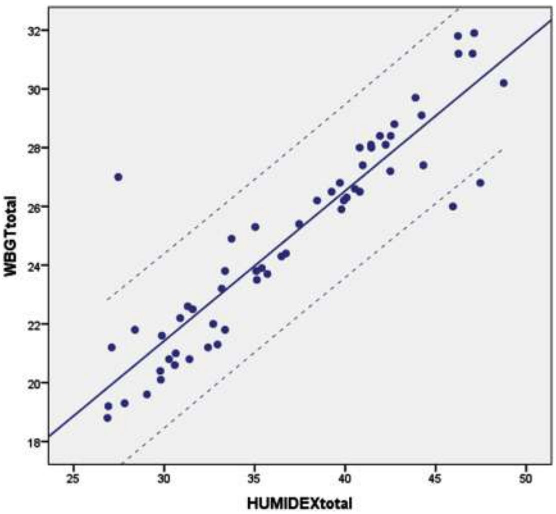

Fig. 1. The scatter plot of WBGT vs. Humidex indices (WBGT-total=6.11+0.51 Humidex-total) (R = 0.912, $P < 0.001$, R2 = 0.831).

had a better performance compared to the WBGT index, in the unit where the values of one of the two parameters of humidity and temperature (hot processes) were higher than in the other units. The effect of humidity and temperature in the correlation between the two indices based on defined ranges of temperature and humidity was evaluated. The correlation between the two indices was in different ranges of temperature or humidity, and the obtained agreement coefficient (Kappa=0.3). WBGT and Humidex have a relatively poor agreement, and by considering WBGT as the standard and index, the sensitivity and specificity of Humidex were 51% and 100%, respectively. However, by considering the Pearson correlation coefficient, a very high agreement was observed between the two indices (R=0.9). The study by Heidari et al. showed that regardless of the type of climate (arid or semi-arid), in the studied temperature and humidity range, Humidex can be applied as a suitable substitute for WBGT, and it is compatible with tympanic temperature as a physiological response against heat. Evaluation of low temperatures or extremely hot temperatures (above 30°C) accompanied by high humidity (above 30%), focusing on tympanic temperature or other valid indices will provide more realistic results of thermal conditions [14]. According to the results of the WBGT index, 23.7% of the measurements in different manufacturing parts fall into the slight category and the range of below 32°C; however, based on the results of Humidex, 25.4% of the measurements fall in the slight category, 22% fell in moderate category and 11.9% of them fell in the strong category. Compared with the WBGT index, Humidex works better on the evaluation of the risk of heat stress in settings with moderate and extreme heat stress. The study conducted in Washington during the years 1980-2010 showed that as the air temperature increases above Humidex >36, 1.69 percent of deaths increase [24]. Despite its limitations, Humidex is regarded as a suitable and popular index in the evaluation of heat stress in outdoor settings [25]. Golbabaei et al. reported that there is a moderate correlation between physiological strains and WBGT [26]. In a study conducted in Korea regarding thermal stress in outdoor settings by using different indices, WBGT was more sensitive in the evaluation of heat stress in outdoor settings. Based on the results, there is a very high correlation between the two indices (R=0.912, P<0.001) [27]. In the study Haidari et al., similar results were obtained, which indicated a high correlation (R=0.98) between WBGT and Humidex indices [14]. The correlation between WBGT and Humidex indices was investigated based on threshold limit values (TLV) defined for these indices. A high correlation was found between the two indices (R=0.912, P<0.001) and also a relatively poor agreement was observed between the two indices (Kappa-Value = 0.298, P=0.001). One reason may be that in cases where WBGT values are below 28°C and Humidex values are below 35, there will be weak correlations between the two indices (R=0.387, P=0.062); meaning that some values are considered as standard values based on WBGT index, instead, they are recognized to be above standard, based on Humidex. The next reason is that in settings with high temperature and high humidity levels, Humidex works very well in estimating the risk of heat stress and the application of WBGT is quite limited to these conditions. Results of the study by Alfano et al. showed that Humidex often works very well in the evaluation of heat stress in dangerous settings with temperatures above 36°C; however, it has weak reliability in the evaluation of thermal conditions below 36°C in indoor settings and these results are consistent with the present study [28].

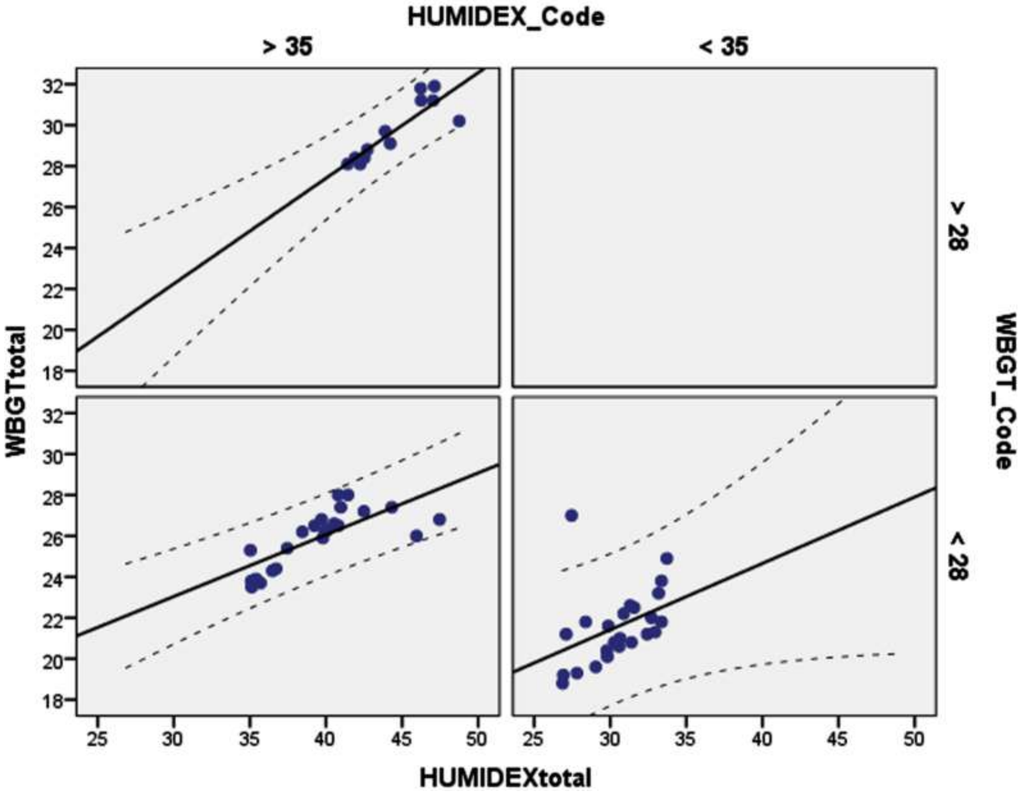

Fig. 2. Scatter plot and regression of total WBGT and total Humidex on the basis of defined categories of their standard values.

5. Conclusions

Humidex serves very well in the classification in terms of estimation of the actual level of heat stress. Results indicated that in indoor settings, when one or both parameters of dry-bulb temperature and humidity are high, Humidex will have a more sensitive compared to WBGT and application of WBGT is quite limited to these conditions. Therefore, Humidex can be used as a suitable substitute -yet with better performance- for WBGT, especially in workplaces with a high potential for heat stress. It is recommended to compare these two indices in different industries and under different climatic conditions. It is also suggested that the results of these two indices, together with the physiological responses of the human body, be examined in the future.

Ethics statement

The study was approved by the Research Deputy of Kermanshah University of Medical Sciences (IR.KUMS.REC.1395.316).

Informed consent

Not applicable.

Acknowledgments

The authors would like to thank the manager and workers of the tile factory for their help in carrying out this study.

Conflict of interest

The authors declare no conflicts of interest.

Funding

This study is the result of a research project approved by the Research Department of Kermanshah University of Medical Sciences (grant number: 95448).

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